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UNDERSTANDING TELERADIOLOGY

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Executive Summary

Ronald B. Schilling, Ph.D.

This handbook is the second publication of the SCAR Technology Forum. The first publication, "*Understanding PACS*," was published in 1992. The purpose of both publications is to provide the reader with a basic understanding of the essential principles associated with these important areas in medical imaging. In addition, the handbooks are designed to serve as resource materials to assist the reader in determining where to go for more detailed information.

In today's environment it appears that the move to managed care and regionalized health care is inevitable. Key to the success of these endeavors is the accurate and timely transmission and interpretation of medical information. Teleradiology is a requisite technology to achieve these goals. Teleradiology has already proven to be the first application of PACS to reach fruition. It is hoped that this handbook will serve as an indispensable guide and reference for those presently in or about to enter the exciting world of teleradiology.

Each chapter in this publication focuses on the key issues and attempts to provide a high degree of clarity. Chapter 1: "Introduction" addresses the history and development of teleradiology, from initial revelations to present day achievements. Chapter 2: "The Teleradiology Attraction" discusses the practice benefits and economic imperatives encouraging the development of teleradiology. Chapter 3: "Technical Factors in Teleradiology" provides an overview of the capabilities of typical teleradiology systems and serves as an introduction to the specifications. The final chapter, Chapter 4: "General Considerations" details the considerations of interfacing the teleradiology system to other parts of the network, and the cost of acquiring and operating the system.

The "Suggested Readings" are chosen for their contemporary applicability and their contribution to understanding the technology, applications and issues involved in teleradiology. Accompanying each reference is a paragraph discussing the relevance of the cited work. The "Glossary" defines terms pertinent to the clinical application and technology of teleradiology components and systems.

CHAPTER I

INTRODUCTION

Joseph N. Gitlin, D.P.H.

Interest in teleradiology as a practical, cost effective method of providing professional radiology services to "under served" areas began twenty years ago when telemedicine was considered an alternative to recruiting medical specialists to isolated communities. At the same time, radiologists who provided services to multiple hospitals in sparsely populated areas saw an opportunity to increase their productivity by decreasing their time spent in "circuit riding." Initial efforts to provide image interpretation services via teleradiology were dependent upon digitizing analogue images produced at a hospital or local clinic by focusing a television camera on x-ray film and transmitting the data over conventional telephone lines to a medical center. There a specialist viewed the images on a television screen and discussed the interpretation with the general practitioner, paramedic, or nurse practitioner at the patient location. The early telemedicine systems were useful in many cases where they facilitated local patient care and avoided the unnecessary transport of patients to distant hospitals. However, the evaluation of these systems regarding their use for the primary diagnosis of radiographic images identified many technical deficiencies in the hardware, software, and telecommunication links.[1] Image resolution was inadequate, transmission speed was slow, storage and retrieval of data were expensive, and formal reporting was delayed.

Since there were potential medical and economic benefits to military personnel at small installations and ships at sea, that had no radiologists, the Department of Defense supported several pilot programs to evaluate the feasibility of utilizing new technology to solve the hardware and software problems identified in the earlier studies. Equally important in the Department of Defense sponsored studies were the objectives to define the level of functionality needed to support teleradiology for primary diagnosis of radiographic images and specify the systems' requirements to fulfill the concept of "filmless radiology."

By 1985, the efforts of government, academia and industry had advanced the state-of-the-art to the point where teleradiology was technically feasible, but did not have widespread acceptance among radiologists and other physicians, nor had its cost-effectiveness been demonstrated.[2] Limited success had been achieved in marketing inexpensive systems for "on-call" screening of images by radiologists at home and the remote interpretation

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[1] Gayler BW, Gitlin JN, Rappaport WH, Skinner FL. A Laboratory Evaluation of Teleradiology, Proceedings of the Sixth Conference on Computer Applications in Radiology. June 1979; 26-30.

[2] Gitlin JN. Teleradiology, Use of Computers in Radiology, Radiologic Clinics of North America. Vol. 24, No. 1, March 1986, 55-68.

of CT and MR cases by radiologists in group practice had begun. In most hospital applications, teleradiology was generally considered a subset of the broader image management concept referred to as Picture Archiving and Communication Systems (PACS). The major technical advances applicable to teleradiology were associated with improvements in components such as film digitizers, storage and retrieval systems and workstation monitors. Equally important were advances in telecommunications which made it possible to transmit diagnostic images at data rates in excess of one megabit per second.

Thanks to the telecommunications and computer industries, in 1990 it appeared that both teleradiology and image management systems had all of the hardware and software needed to proceed with addressing the issues of clinical acceptance and cost-effectiveness.

There are many factors related to the clinical acceptance and the cost-effectiveness of teleradiology. They include radiologists' confidence in the accuracy of image interpretations using electronic displays, efficiency and productivity when using workstations, the use of destructive data compression algorithms, reimbursement for consultation and second opinions, differing interstate licensure requirements, competitive ethics, and economic considerations related to system purchase and maintenance. Recently, many hospital administrators and radiologists have deferred decisions on new equipment until more is known about the impact of health care reform.

As of this writing, the most important factor related to clinical acceptance of teleradiology is its utility in facilitating the primary diagnosis of conventional radiographic examinations performed at distant sites. Many well designed comparative studies of screen and film interpretations have shown that the accuracy of screen readings is significantly lower than film viewing and that the reader's confidence in the interpretation is adversely affected by the electronic workstation. These studies have indicated the need for improved contrast and spatial resolution of the images and increased luminance of the display monitors. The data also have emphasized the need for more intensive user training and the use of available manipulation functions when viewing images on the workstation.

With regard to economics, the most important issues are the relatively high cost of image display equipment with adequate functionality and the recurring costs of transmission media capable of the speeds needed to provide prompt consultation on data intensive medical images. The latter issue may be resolved soon by the Federal High Performance Computing and Communications (HPCC) Program, which is supporting the development

of high-speed networks that will be available to transmit medical images to improve health care.[3]

While there are many issues to be resolved before teleradiolgy is routinely available in health care delivery, progress has been made and increasing interest in the technology is being shown by pathologists, emergency medicine physicians, HMO's, and third party payors. Where implementation of teleradiology is dependent upon installation of image management systems in hospitals and medical centers, acceptance of the technology will be facilitated by the recent demonstrations of the network version of the ACR-NEMA Standard Version 3.0 (DICOM) and its proposed adoption as an international standard. It is anticipated that in 1995 all manufacturers of imaging equipment and related devices will be able to provide ACR-NEMA compatible products. As part of the Centennial celebration of Roentgen's discovery of x-rays, teleradiology will be an important example of science and technology's contribution to health care.

[3] Office of Science and Technology Policy, Executive Office of the President. High Performance Computing and Communications: Toward a National Information Infrastructure, 1994, (Washington, D.C. 20506).

CHAPTER II

THE TELERADIOLOGY ATTRACTION

Robert M. Allman, M.D., Ray F. Kilcoyne, M.D., and Roger Shannon, M.D.

The most alluring attribute of electronic medical imaging may be the prospect of viewing radiographs instantaneously from remote sites. No delay, no lost films, not having to join a borrower's queue, just summon and behold. With electronic imaging the geography would no longer seem to pose a barrier to quick, easy, cost-effective service. For anyone who has ever covered a busy radiology practice, teleradiology's ability to surmount the obstacles of serving a rural hospital, an office across town, a satellite installation, or the emergency room at night, has an immense appeal.

What is teleradiology?: It has been defined as "the electronic transmission of radiologic images from a radiology site to a distant viewing station where interpretations are made."[1] Distant sites such as those listed above come to mind first, but there are many places within large health institutions that are also difficult to cover, not only for interpretation but also for distribution and consultative discussion. The intensive care units, clinics, conference rooms, classrooms, extended care areas, research centers and mobile units are examples. The appeal of conquering these spatial barriers together with advancing digital technology in modalities such as CT, ultrasound and MRI, has led to a growing number of "teleradiology" solutions for practice problems. Over the years, the technology has matured to an extent that is considered to be practical and affordable for many clinical situations.[2] The entrance of large companies into the field is indicative that the technology shows promise.

In addition to practice benefits, there are economic imperatives encouraging the development of teleradiology. Radiologists and administrators recognize market value for both buyer and seller. The seller has the prospect of increasing the quality of service to patients by electronically extending the radiologist's consulting service to areas where constant physical presence is simply not possible, cost-effective, or convenient. This increases the market scope in which purveyors of health care can compete. From the buyer's perspective, this "opening up" of the market frees "hostage" institutions to seek competitive bids for coverage, thereby reducing contract costs. Success in reconfiguring these service patterns should be accompanied by better quality of care and better access to the health care system by the patient.

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[1] Glossary. Understanding PACS: Picture Archiving and Communications Systems. SCAR, 1992, p.32.

[2] WR Hendee, JE Youker. Teleradiology: the Maturation of a Technology, Applied Radiology. 1992, Vol. 21, 13-16.

As large health care organizations develop regional alternatives to the classic *competitive* model, the ability to transmit patient data in every form--text, image, graphics and sound--will make it possible to integrate patient information with care teams regardless of location. The development of teleradiology along with other electronic innovations will enable the design of local and wide area networks that will provide the infrastructure of true "telemedicine." But application of this technology, like most innovation, will exact a price in the need to shift attitudes and to recast habitual work patterns. Electronic imaging, by nature, reduces assembly time of the study, making it available for interpretation almost immediately. With this comes the possibility of smoothing patient flow, reducing patient workup time and inserting a completed radiological interpretation into the dynamic decision stream. Following on the heels of possibility, of course, comes the demand that it be realized.

When the radiologist can be in all places at all times, what are some of the expected benefits?

First on the list must be the improvement of patient outcomes. This will be brought about in many ways, but foremost is timely access to skilled service. Specialty diagnostic teams will reach to many remote sites convenient to the patient instead of requiring long distance travel to receive consultative services. This outreach not only augurs well for better medical results but also for better patient accommodation and satisfaction.

By reducing the time to conduct services as well as to deliver them, teleradiology has the potential to increase the efficiency and productivity of many members of the radiology team. Radiologists, technologists, assistants and clerks all will acquire better control of the processes in their charge and, thereby, will be able to turn out a larger volume of high quality work.

Integrally associated with teleradiology are a number of attributes of electronic digital radiology in general. These contribute strongly to the appeal of rendering service by teleradiology. Some of the particularly appealing qualities are:

- The ability to keep detailed records of technical factors, examination events and personnel with respect to time. This provides a new level of technical oversight and quality control which can be focused on the teleradiological procedures in particular, which can be folded into the continuing quality improvement interests of the department, clinic or hospital in general.

- The capability of using the great latitude of digital radiography to adjust image formation factors. Digital radiography enables manipulation of images to achieve specialized diagnostic objectives, and it furnishes a means to exercise tight control over image characteristics.

- The ability to handle images as intangibles. Electronic image storage and retrieval provide a different orientation towards image library functions than does traditional film management with its tangible, physical images. Performing radiology at or with images from remote sites has always been a problem of identifying, recording and keeping track of the "foreign" films. Correlation of these images with records from other sources has been a major challenge. With electronic imaging systems, particularly if integrated with an electronic hospital information system, the possibility of accessing all needed information for sophisticated analysis and interpretation of radiologic studies offers particular appeal to the responsible radiologist.

- Finally, the ability to access electronically various segments of the patient record, and various decision support services. These may be either part of the hospital complex or distant services accessible through networks such as Internet.

If teleradiology has so much to offer and has proven its value, why hasn't there been more use of teleradiology in practice today?

So far teleradiology has not been driven by the more common factors that influence the introduction of a new technology. Radiologists and others interested in improving health care delivery and decision support with imaging modalities are more at ease with technology advances that either improve the quality of characterizing tissue or reduce costs. It has been difficult to demonstrate that teleradiology (by itself) will do either. Most implementations to date have been (1) in the interest of providing broader coverage by radiologists, i.e. reducing time and/or distance in review of images, (2) in the interest of preserving turf, or (3) to provide unread images to locations where non-radiologists can use images for diagnosis or treatment evaluation on their own without the benefit of radiologist consultation. These uses hardly qualify as traditional improvements in quality image interpretation or in cost savings.

What are the current attitudes/perceptions that will have to change to promote further acceptance of teleradiology?

The value of radiology as part of decision support to diagnosis, therapy and prognosis is perceived differently at many levels by patients, referring physicians, hospital admin-

istrators and radiology department staff. The factors determining the quality of this multidimensional specialty are not readily apparent in their entirety, except perhaps to those who have held unique positions from which to view the entire system. For example, consider only four attributes in radiological imaging that influence quality characteristics: devices and other equipment (the technology), the image medium (traditionally film-screen), radiological diagnoses (the report), and informatics (communication). Attitudes inside and outside departments can be characterized by the foremost element concerning a critical observer of department quality.

If the focus of the observer is on having the newest and/or best equipment available, then the pitfall is an attitude that favors infatuation with the gadgetry of radiology and computers. If high quality of the images is the overriding goal, then a pretty picture at all costs becomes the benchmark and the compulsion. If the diagnostic report drives the system, then the result too often is overly descriptive (wordy), unreadable, occasionally meaningless and arrives relatively late in the decision support process. Only when all of the above culminate in an attitude where communication in a timely fashion (vis-à-vis medical informatics) permeates the scene will teleradiology be perceived by a majority of individuals as essential to the future of radiology. The criteria for judging teleradiology must shift from the traditional "high quality image characterization of tissue" to medical informatics where relevant, accurate, informative and meaningful, timely decision support is perceived as the gold standard by which to judge the practice of radiology.

References:

SJ Dwyer III, BK Stewart, JW Sayre, JC Honeyman. Wide Area Network Strategies for Teleradiology Systems, Radiographics 1992. Vol. 12, 567-576.

WR Hendee, JE Youker. Teleradiology - The Maturation of a Technology, Applied Radiology 1992. Vol. 21, 13-16.

AR Shonfeld, Ph.D. Teleradiology-Examining its Impact on Image Management, Decisions in Imaging Economics. Vol. 2, No. 4, GE Medical Systems, 20-25.

CHAPTER III

Technical Factors in Teleradiology

Alan H. Rowberg M.D., Samuel J. Dwyer III, Ph.D., and Brent K. Stewart, Ph.D.

A full description of details of all the technical factors involved in selecting a teleradiology system is beyond the scope of this document, but is well described in a booklet published by the American College of Radiology. The sections which follow give an overview of the types of capabilities provided by typical teleradiology systems, and serve as an introduction to the detailed specifications provided in "A Guide to Teleradiology Systems."[1]

Image Acquisition

The process of sending a radiological image to a remote viewing site begins with capturing an adequate representation of the image and transferring it to a digital computer. This image acquisition process can be accomplished by any of a variety of methods, depending on the hardware purchased with the teleradiology system, and the type of image to be transmitted. Some systems will use more than one method, such as video image capture for CT images and a laser film scanner for radiographic film images.

In terms of ease of use, the simplest method for capturing images is to digitize a film by scanning it with a light beam, and recording the amount of light which passes through the film. This is also the most flexible method, because it can be used to capture almost any type of image, by first printing the image on a film.

Most radiology departments routinely print the majority or all of their images on film. Many radiographic images, such as chest or abdomen x-rays are already on film, and CT or MRI scans are usually photographed or "printed" onto translucent films for viewing on a film alternator. Even images that are cine sequences, such as real-time ultrasound or cardiac cineangiography, can be printed as a series of static images.

Film digitizers are flexible because they can be used with any and all radiographic modalities in the hospital or clinic, and do not require specialized connections, as might be required to connect a video image digitizer to a CT scanner. The laser film digitizers are the easiest to use of the film digitizers because they can scan the film with a narrow light beam which gives high spatial resolution, and with an excellent ability to resolve details in both the lightest and the darkest areas of the film, often resolving 1000 shades of gray or more.

[1] A Guide to Teleradiology Systems, American College of Radiology, 1993.

Other methods for scanning the film include the use of a Charge Coupled Device, called a CCD, which may be thought of as a row of tiny photocells that are scanned across the film, while a uniform bright light illuminates the film. Alternatively, a video camera can be focused on a film mounted on a viewbox and used to digitize the image, but this limits the image quality significantly.

A video image capture device is typically a computer circuit board placed in a computer. This board measures and digitizes the video signal voltage waveform going to an image display, such as a CT scanner console video monitor. These digitizers may be used to capture any video image, including a television camera pointed at an x-ray film mounted on a viewbox. However, these devices tend to be more troublesome to operate, since they require careful attention to lens setting, such as focus and f-stop, in addition to difficulty in providing uniform illumination of the x-ray film.

A more modern method of interfacing to digital radiographic modalities is the use of an all-digital connection between the modality computer and the teleradiology system computer, probably using the Digital Image Communication in Medicine (DICOM) standard, developed through a cooperative effort of the American College of Radiology and the National Electrical Manufacturers Association (ACR-NEMA).

Image Compression

The process of compressing images for more compact storage or faster transmission is associated with both uncertainty and controversy. In some circumstances data compression must be totally reversible, so that decompression will reproduce exactly the original image. However, more efficient methods result in an image that can be diagnostically equivalent to the original image. While compression may reduce the size of a CT image by only a factor or three or four, a chest x-ray may be compressed by a factor of 20 or more, without the loss of clinically significant information.

There are a variety of different methods for data compression, some specified by the DICOM standard. Methods of data compression that can regenerate the original image precisely are said to be "lossless" while methods that use more image compression and result in images that are diagnostically equivalent are termed "lossy" data compression methods. While they may not provide a perfect rendition of the image, the representation of the decompressed image may be adequate for the purpose of the teleradiology system.

Image Storage

Data storage is accomplished by a variety of methods in different systems, and must often be tailored to the needs of a specific user of these facilities. Here we refer to short-term storage of images for teleradiology and not to the large long-term storage in a PACS archive.

Although the typical teleradiology system does not require a great deal of image storage, there are some circumstances in which substantial image storage is extremely useful. On the transmitting end, there may be times when one wishes to capture or acquire a series of images but not transmit them immediately. Also in some circumstances there may be a problem accessing the telephone line, e.g. when the receiving end may be giving a busy signal. However, the need for archiving usually arises when the user wishes to acquire images at a faster rate than they can be transmitted or transmit them at a later time for the convenience of the receiver.

At the receiving end, a small amount of image storage is very useful to allow review of recent images a day or two later, in addition to being able to compare several images from the current examination or to compare the current with related examinations.

The specific type of this image storage is not critical, but the number of images stored does depend on the size of the storage facility, often a hard disk, and on the amount of data compression which is applied to the images before storage. In some systems, the images are decompressed as they are received and are stored on the hard disk in decompressed format. While this provides for the storage of fewer images, the images may be recalled and displayed more rapidly, because the additional decompression step is not required before each viewing.

Image Transmission

Image transmission is usually done over ordinary dial-up telephone lines, using computer modems to transmit the images. These modems are frequently inside the teleradiology system, and the manufacturer ensures that the receive modems are properly matched to the transmit modems with respect to speed of transmission, data compression, error detection and correction procedures. Sometimes, image transmission can be accomplished over a local area network, such as a hospital network or an Integrated Services Digital Network (ISDN) circuit provided by the local telephone company.

Viewing the Images

The process of displaying images involves the use of specific display technology, optimized for use in a given teleradiology application. The demands made on a system used for primary diagnosis are different from the demands made on a system used to monitor the completeness of examinations. The display quality is one of the factors which determines the usefulness of the received images, and the nature of the diagnostic information that may be extracted from the images. Although most images transmitted using teleradiology are black and white, there may be circumstances, such as when nuclear medicine images are transmitted in color. The use of a color display in a teleradiology terminal may provide some problems, because the color display screen is comprised of tiny luminescent dots alternating between red, green, and blue in color. The interaction of these dots with the pixels in the medical image may result in blurring of details at the edge of the image and a slight reduction in the resolution capability of the overall system.

Luminance describes the amount of light emitted by the CRT display surface and affects the human eye's response through both the acuity of the eye and the detection of luminance differences. Commonly available monitors have a maximum luminance value of 50 foot-lamberts (ft-L) and some of the newer grayscale monitors have luminance levels of over 160 ft-L, but are still not nearly as bright as viewboxes, which have a luminance of over 500 ft-L.

In some teleradiology systems the images are printed on film at the receiving end, so they can be viewed on conventional film alternators or viewboxes, and filed with other radiographic examinations.

Part of the functionality of a teleradiology workstation is provided by the software, and includes features such as brightness and contrast adjustments, magnification, and edge enhancement. Most teleradiology viewing applications require much less image processing than is available on the typical CT or MRI scanner. Of greater interest is the speed of image display, the number of images which can be displayed simultaneously, and the convenience of paging through a series of images.

CHAPTER IV

General Considerations

Alan H. Rowberg, M.D.

The consideration of factors surrounding the acquisition and use of a teleradiology system must include interfacing the system to other computers through standard interfaces, the cost of acquiring and operating the system, and the ease of accomplishing upgrades to the system.

DICOM

The combined efforts of the American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA) have led to the development of the Digital Image Communication in Medicine (DICOM) standard, which provides a format for communication among medical imaging devices. This standard has developed and matured over a period of time, and the numerous demonstrations of practical capability in recent years have confirmed the viability of this approach. This is important in teleradiology, because it gives an additional method for linking the teleradiology equipment to the imaging modalities at the image source. The use of this direct digital connection not only ensures image fidelity, but also allows access to the full resolution of the original image, such as the wide contrast range in CT scanner images.

The medical imaging community has been working hard on the development of image communication standards for PACS. ACR-NEMA Version 2.0 has been used for some communication between imaging equipment and other devices, such as display workstations. The latest version of the standard, ACR-NEMA Version 3.0 (DICOM), includes network communication capability.

While this standard can be used to connect a CT scanner to a teleradiology workstation, at the image transmission end, it is not directly applicable to the teleradiology link itself. That is, a teleradiology system may use a DICOM standard connection to the CT scanner, but a proprietary method of transmitting the image over telephone lines using modems to the receiving workstation. This use of proprietary communication techniques prevents medical facilities from purchasing a transmitting station from one company and receiving workstations from other companies. This is particularly significant because it greatly limits the upgrade possibilities and may require that the user replace all of the components in order to upgrade at a later date, even from the same equipment vendor.

It would be possible to use the image communication capability provided under the DICOM standard over the telephone connection, although transmission might not be as fast as

with some of the proprietary protocols. However, if a teleradiology workstation were capable of using either the proprietary or the DICOM method to transmit images, the user would have a wider range of upgrade options in the future.

There are many decisions which must be made in the course of selecting the method of interfacing to a teleradiology system. If an interface to a digital imaging modality, such as CT or MRI is required, then the user may have a choice of using a video frame grabber to capture the images, or using a direct digital interface. While the video connection may be faster and more flexible, there are limitations to the dynamic range of the acquired images, and the viewer will not have control of the window width and level of the transmitted images.

System Cost

The cost of a teleradiology system varies widely depending upon the amount of capability desired, the number of teleradiology workstations to be purchased, and the amount and type of preexisting equipment available for use. If a PACS system is available with the capability of transmitting images remotely, the cost of the teleradiology equipment may be limited to the purchase of one or more remote teleradiology workstations. If there is a requirement to store a large number of examinations, handle images with high resolution or transmit them very quickly, then the cost will increase.

The value of a teleradiology system is difficult to measure, because it is not amenable to typical cost/benefit analysis. Very often, the benefits are improved patient care, improved service to referring physicians, and more rapid response to clinical needs. Because these benefits tend to be intangible, it may be difficult to quantify them and apply them to an evaluation of the life cycle cost of the proposed teleradiology system. Too frequently, the true cost of a teleradiology system is seen only after the purchase of a system that does not satisfy the requirements or is incapable of growth over time.

The Cost of Communication

There is a wide variety of types of telecommunications systems that may be used to support teleradiology applications, and each has costs which vary as widely as the benefits and features they provide. The simplest connection is a dial-up modem connection over ordinary telephone lines. These are easily established, and there is little problem with telephone line noise in most circumstances. While the modems selected limit the speed of

image transmission, the transmission times can be under one minute per CT image with data compression, and even long-distance transmission of images may be feasible.

The simplest method of transmission is unidirectional, such as with images being transmitted from a hospital to an on-call radiologist. With more elaborate systems, it may be possible for a radiologist to discuss a case with another physician, with each person having the ability to move a cursor over the image, and have the cursor automatically move on the screen of the distant workstation, so that real-time voice consultation can be supplemented by interaction with the images, perhaps including brightness and contrast changes for image viewing, and text or graphical annotation over the images. More sophisticated systems may provide video conferencing, so that the radiologist may also interview the patient at a distance, and have a two-way video conference with the referring physician, as they discuss the approach to diagnosis and management of a difficult case.

Where there is the requirement for rapid transmission of a large number of images, the transmission network must be configured with faster methods of digital image communication. Within a city, T-1 telephone lines may be used. These are dedicated connections leased from the telephone company or other carrier, and provide 1.5 million bits per second of digital communication capability, approximately 100 times that of a voice-grade telephone connection using a modem. Such a connection over the distance of a few miles is likely to cost between one and two dollars per hour, and can be effective if it is used many hours per day. However, the user effectively pays for such dedicated lines 24 hours per day, so it may not be cost-effective if used intermittently.

Faster methods of communication may be provided by using microwave links, satellite connections, fiber optics, or newer high-speed digital switching technology, such as the Asynchronous Transfer Mode (ATM) devices being installed in some telephone company facilities. Connections over longer distances are more affordable if some form of switched service is used, so that the user pays for the connection only while images are actually being transmitted. Such services are widely available using T-1 rates, in fractional steps, even over long distances.

Overall Cost

The cost and management issues which surround a teleradiology application are complex and difficult to predict. Many facilities have had very successful installations, while some have had unsatisfactory experiences. These cost and management issues are often not

reported in the teleradiology literature, and improvements in technology lower the usefulness of older reports.

To some extent the value of teleradiology depends on the workload and clinical protocols in place at the clinical facility, coupled with user experience in equipment reliability and learning the new skills required to use this technology effectively.

Upgradability

Commercial teleradiology systems vary in their upgrade potential from relatively simple systems that are part of a narrow product line, to entry level systems that can easily grow to add more capability, eventually becoming a significant portion of a total PACS system. Users may wish to upgrade only one aspect of the system operation, or purchase a combination of capabilities to increase functionality. As system use grows, faster methods of telecommunication may be required, and the ability to upgrade to a faster modem, or the use of specialized telecommunication capabilities, such as dedicated telephone lines, may be desired.

Frequently, there is a need to store images for several days, or to accomadate a large number of images at one time. This may require either the expansion of the existing disk storage capability, or the addition of a different method of image storage. There may be the need to add additional display capability to view more images simultaneously, or to interpret images with higher resolution. In some circumstances, the initial teleradiology system provides for connection only to a limited number of image modalities, and the addition of a wider variety of imaging devices may be required in the future.

Unfortunately, very few systems are compatible with teleradiology equipment manufactured by other companies. If an upgrade cannot be accomplished by the current vendor, there may be the need to change vendors, and replace much or all of the old equipment to accomplish an upgrade. Medical facilities should carefully evaluate teleradiology systems not only in terms of their present need, but also reasonable projections of future requirements.

Systems that require the transmission of conventional film images will use some method for digitizing the images. The least expensive equipment uses a television camera aimed at a lightbox, where the film is placed. These systems tend to be difficult to operate, and the user must manually adjust both the film placement and the camera settings (zoom, focus, and f-stop) to obtain a satisfactory image. Even then, the full brightness range of

the image is usually not obtained, and it may be necessary to capture and transmit the image at several settings.

The display capability which the teleradiology image viewing system offers largely determines how image viewing is done. If the system has a large display, perhaps up to 2000 x 2500 pixels, then a full chest image or 20 CT images may be viewed at one time. However, a VGA display usually has only 640 x 480 pixels, and limits viewing to one CT scanner image, or a portion of a radiograph at full resolution, although the image may be minified to fit on the screen with reduced resolution.

The number and type of images to be transmitted during a typical workday will determine how much image transmission capability should be purchased. While images may be transmitted overnight in some cases, making image transmission speed a less important factor, usually the images are transmitted during the working day or during night call coverage, and must be transmitted and viewed quickly.

Some teleradiology systems rely on printed images at the receiving end, and these may be most compatible with existing methods of routing images and patient studies to diagnostic viewing areas, using current methods of image display, such as film alternators. The modern laser film printers (often called laser cameras) can print images with high resolution, and for CT and MRI films, may actually match the originals in image quality. Each image type has its unique size and brightness characteristics, and may be displayed in different ways on different viewing workstations. While a viewer may wish to see several images simultaneously on a multiscreen PACS workstation, it may be necessary to display only one image at a time on a smaller image viewing station.

While the amount of data compression to be used may be decided on a case-by-case basis, it is more likely that one method will be applied to all images, making it easier to use the system on a routine basis. Even though the amount of data compression cannot be adjusted for each clinical situation, it is less likely for a gross error to occur in the amount of data compression if these factors are selected automatically.

Some of the features that improve the ease of use of a system include a laser film digitizer instead of a video camera and a very large, high-resolution screen for image viewing. While these add to the cost of the system they provide a large benefit in overall quality, in addition to improving the ease of use. Other features such as additional local storage may also make major contributions to ease of use and add little to the total cost of a system.

A well-designed system can scan an image, dial a telephone connection, transmit the image, disconnect the telephone, and then record the successful transmission in a teleradiology log. A different system with a similar price may require that the user stay at the system, and type in one or more commands to accomplish each of these steps.

GLOSSARY

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The following terms have been defined in the context of medical imaging to help the reader understand the technology described in this handbook.

Algorithm: A step-by-step procedure designed to accomplish a specific purpose, e.g., to solve a problem. One or more algorithms may be converted into a computer program.

Annotation: A process of adding text or graphical information to an image.

Analog image: An image, usually on film, in which spatial and contrast representations of structures vary in a continuous manner.

ATM: Asynchronous transfer mode; a new telecommunications technology, also known as cell switching.

Bit: Binary digit; the smallest unit of digital information that an electronic computing device handles. A bit can have one of two values, 0 or 1. All data are processed by computing devices as bits or strings of bits.

Byte: A string of adjacent bits used to represent a character or value; usually 8 bits in length.

Circuit riding: The movement of a radiologist from one location to another for the purpose of providing diagnostic imaging services to patients at health care facilities that do not have a radiologist on-site to provide such services.

Computed radiography (CR): A method of producing digital radiographic images using a storage phosphor plate (rather than film) in a cassette. After the plate is exposed, a laser beam scans it to produce the digital data that are converted to an image.

Cursor: A symbol displayed on a monitor to point to a feature or an item. The operator uses the cursor to select the feature or item to be manipulated by using specific computer commands.

Data compression: The process of encoding data representing an image to reduce data storage space requirements and image processing and transmission times. With some

encoding methods, no information is lost; such methods are described as "reversible," "non-destructive," "lossless," or "bit-preserving" data compression. With other methods, some information is lost in the encoding process; the loss may or may not be diagnostically significant, depending on the specific clinical issue that is being addressed, the imaging study performed, and the encoding process used. Such methods are described as "irreversible," "destructive," "lossy," or "non-bit preserving" data compression.

Dial-up telephone lines: Conventional telephone lines ordinarily used for voice communication, but also suitable for computer communication if additional equipment, for example a modem, is used.

DICOM: Digital Imaging and Communication in Medicine standard developed as a result of collaboration between the American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA). The standard, also known as ACR-NEMA Version 3.0, facilitates communication among digital imaging devices and related components that may be produced by different manufacturers. Sections of the standard have been tested and demonstrated, and the standard is proceeding toward official international adoption.

Digital: Pertaining to the representation of medical images or other entities by values that vary in discrete steps.

Digital radiography, electronic digital radiology, electronic imaging: Alternative phrases for digital imaging.

Digitizing: The process of converting analog information (e.g., film density that varies continuously) into data elements that vary in discrete steps (e.g., discrete shades of gray).

Direct digital interface: A device that facilitates the transfer of data from a digital imaging modality to a system that may transmit, store, retrieve, process, and/or display the image data.

Dynamic Range: The ability of a communications or imaging system to transmit or reproduce a spectrum of information or brightness values.

Film alternator: A motor driven device that displays multiple films for interpretation and moves them under the control of an operator. An alternator may be thought of as multiple banks of moving view boxes.

Film digitizer: A device that converts the analog information on a film into digital data. It permits conversion of the image on the film into an array of pixels (picture elements) that corresponds to the digital image displayed on a monitor. Each pixel has a size that reflects the spatial resolution of the digital image and a shade of gray that reflects its contrast resolution.

Filmless radiology: The practice of radiology without film, using devices that acquire digital images and related patient information and transmit, store, retrieve, and display them electronically.

Gray scale: The number of different shades of gray that can be stored and displayed. The number is determined by the number of bits assigned to each pixel and equals 2^n, where n is the number of bits. For example, a system that has 8 bits assigned to each pixel can display 256 shades of gray.

Hard disk: A type of magnetic disk drive used to store digital image data. It is often linked to display equipment to provide quick viewing of a relatively large amount of data.

ICU: Intensive care unit.

Image communication standard: A generally accepted method of specifying the order and format of data so that different devices can process information in the same way.

Image management system: A phrase synonymous with picture archiving and communication system (PACS).

Imaging modality: A device used to produce a medical image, e.g., computed tomography, magnetic resonance, conventional x-ray.

Image processing: The use of algorithms to modify data representing an image, usually to improve diagnostic interpretation. As an example, the window width and level of an image may be modified to visualize certain anatomic structures more effectively.

The window width is the range of the gray scale of the image appearing on the screen; the window level is the middle value of the gray scale range.

Informatics: The science of information and information technologies, including information generation, transmission, processing, management, use, and meaning.

Internet: A large international computer-based digital communications network that is available to many academic institutions, government agencies, businesses, and individual users. The name reflects the fact that it is a large network made up of interconnected smaller networks.

Luminance: The amount of light given off by an object expressed in foot-lamberts. When luminance is perceived, it is called brightness. Although the terms luminance and brightness are often used interchangeably, it is not precise usage.

Microwave link: A communications system that uses very high frequency radio signals to transmit data.

Modem: Modulation/demodulation unit. A device that permits the communication of computer-based data over telephone lines.

"On-call" radiologist: The radiologist outside the health care facility who is responsible for providing radiologic services, usually at night and on weekends and holidays.

Patient outcome: The result of the health care process in terms of impact on the patient.

Picture archiving and communication system (PACS): A system that acquires, transmits, stores (archives), retrieves (from storage), and displays digital images and related patient information from a variety of imaging modalities and communicates the information over a network. It includes the potential for image processing, for linkages to radiology and hospital information systems, and for alternative methods of information input and output, e.g., input through speech recognition systems. Teleradiology may be thought of as a specialized application of PACS or may be a component of a large PACS that has local and distant communications capabilities.

Pixel: The fundamental picture element of a digital image. An image is formed when a large number of pixels are arranged to form a matrix. Each pixel is assigned a specific shade of gray or color.

Primary diagnosis: The official definitive interpretation of a medical imaging study.

Resolution: Spatial resolution refers to the ability to distinguish between adjacent structures. Contrast resolution refers to the ability to distinguish between shades of gray.

Satellite connections: A communications system that uses radio signals sent to and from a satellite that orbits the Earth, often in an orbit that allows the satellite to remain over the same point on the Earth's surface. A satellite allows the signals to be sent and received from far distant points on the Earth's surface where direct transmission is difficult. Satellite communications can also reach remote areas that do not have cables for telephone lines.

Switched service: A telecommunications service, usually based on telephone technology, that switches circuits to connect two or more devices.

Telecommunication: The electronic transfer of information over a distance as opposed to face-to-face communication. The use of telephones for speech and facsimile (FAX) machines for printed material are examples of telecommunication.

Telehealth: The electronic transfer of health information from one location to another for purposes of preventive medicine, health promotion, diagnosis, consultation, education, and/or therapy. Although telehealth is sometimes considered broader in scope than telemedicine, there is no clear-cut distinction between the two.

Telemedicine: Refer to Telehealth, above.

Third party payer: An organization, usually an insurance company or government agency, that pays part or all of a health care bill for services received by a covered individual.

Transmission media: The physical devices used to carry telecommunications signals. Examples are fiber optic cable and coaxial cable.

Turf: The clinical areas and activities considered by a medical specialty to be within its professional domain.

VGA: Video Graphics Array.

Video frame grabber: A device that converts a video (analog) signal into a set of digital values.

View box: The conventional device used to visualize film-based images.

Workstation: A computer based system used to display and manipulate images and related information. A wortkstation often includes multiple monitors on which images and text can be displayed.

Zoom: To enlarge a portion of an image on an electronic display monitor.

The following references were used in defining several of the terms in this glossary:

A Guide to Teleradiology Systems 1993. Prepared by the American College of Radiology (ACR) Committee on Research and Technology Assessment of the Physics and Radiation Protection Commission. ACR, Reston, VA.

High Performance Computing and Communications: Toward a National Infrastructure; 1994. A report by the Committee on Physical, Mathematical, and Engineering Sciences; Federal Coordinating Council for Science, Engineering, and Technology; Office of Science and Technology Policy, Executive Office of the President, Washington, DC.

SUGGESTED READINGS

Philip G. Drew, Ph.D.

ACR Committee on Research and Technology Assessment. A guide to teleradiology systems 1993.

This brief report provides an overview of technology available for teleradiology and consideration of some of the issues surrounding its use.

Arenson RL, Seshadri SB, Kundel HL, et al. Clinical evaluation of a medical image management system for chest images. American Journal of Roentgenology, 1988; Vol 150, 55-59.

Although described as medical image management, this system at the University of Pennsylvania Medical Center(PENN) is actually a teleradiology system, transmitting images from the Radiology Department to an ICU. The group at PENN pays careful attention to system evaluation, and the work reported here is an elegant model of the techniques for evaluation.

Bidgood WD, Staab EV. Understanding and Using Teleradiology. Seminars in Ultrasound, CT, and MRI, 1992; Vol 13; 102-112.

This is a very instructive practical discussion. The authors start from the clinical problems to be solved and discuss the pros and cons of various solutions using teleradiology to improve quality of service to patients by extending radiologists' services to areas where continual physical presence is simply not possible.

Blaine GJ, Moore SM, Cox JR, et al. Teleradiology via narrow-band Integrated Services Digital Network (N-ISDN) and Joint Photographic Experts Group (JPEG) image compression. Journal of Digital Imaging, 1992; Vol 5; 156-160.

The group at the Mallincrodt Institute of Radiology (Washington University, St. Louis) has participated with Southwestern Bell in a demonstration project using relatively inexpensive ISDN transmission, which is too slow for image transmission without compression. Their work demonstrates that irreversible compression is feasible and for the most part acceptable.

Cawthorn MA, Goeringer F, Telepak RJ, et al. Preliminary assessment of computed tomography and satellite teleradiology from Operation Desert Storm. Investigative Radiology, 1991; Vol 26; 854-589.

Among the many spectacular demonstrations of technology during Operation Desert Storm was transmitting images from the battlefield via teleradiology. The military services have a number of special circumstances, of which this is one, that make electronic image management systems particularly valuable to them.

Carey LS. Teleradiology: part of a comprehensive telehealth system. The Radiology Clinics of North America, 1985; 23, 357-362.

Because of their geography, the Canadians have shown much more interest than have American institutions in supporting remote health care facilities. This paper describes teleradiology in the context of telehealth or telemedicine. Such systems may play a greater role in American health care as it becomes more organized in the future.

Dwyer SJ, Batnitsky S, Templeton AW. Teleradiology: costs of hardware and communications. American Journal of Roentgenology, 1991; Vol 156; 1279-1282.

Among its many initiatives in PACS development, the University of Kansas has been responsible for providing image interpretations for some remote military installations using teleradiology over telephone lines. This report describes the system and the costs of operating it, providing excellent guidance for others contemplating support of remote facilities where images are made, but radiologists are not always available.

ECRI, 5200 Butler Pike, Plymouth Meeting, PA 19462. Teleradiology systems, product comparison system. July 1993.

The misleadingly named Emergency Care Research Institute (ECRI) provides among other services comparative data on imaging devices. One of these reports, available for $60, considers teleradiology systems. The reports describe the technology, show photographs of equipment, and present in simple tabular form technical characteristics of commercially available systems. They are an economical and convenient way to learn the rudiments of available systems. They also sell a PACS product comparison for the same price.

Horii SC, Garra BS, Mun SK, et al. PACS and teleradiology of on-call support of abdominal imaging. Proceedings of Society of Photo-Optical Instrumentation Engineers, 1991. Vol 1446; 10-15.

A very common application of teleradiology is using the system for radiologists on-call so that they can avoid trips from home to hospital. This is one of the few papers that discusses this application as it applies to abdominal imaging, primarily by ultrasound. It describes a system at Georgetown University, its clinical benefits and disadvantages, and its acceptance by radiologists and referring physicians.

Jost RG, Blaine GJ, Moore SM, et al. Primary interpretation of ICU radiographs via soft-copy display. Proceedings of Society of Photo-Optical Instrumentation Engineers, 1992. Vol 1654; 416-423.

The Mallinckrodt Institute of Radiology (Washington University, St. Louis) is one of the few places that has used soft-copy (displays on monitors) for primary interpretation

of certain x-ray procedures, namely, those made of patients in ICUs. They have found that, despite theoretical limitations in spatial resolution, computed radiography (phosphor plate) systems using only soft-copy displays do not compromise diagnostic accuracy, and they have advocated this mode for all portable examinations. This paper is an early report describing some of the difficulties that had to be overcome.

Shih-Chung 1, Huang HK. Compression of radiological images with 512, 1024, and 2048 matrices. Radiology, 1986. Vol 161; 519-525.

Because teleradiology over telephone lines almost always involves irreversible image compression, it is important to have some idea of the diagnostic consequences of compression. This is one of the early papers that discusses this matter.

Staab EV, Honeyman JC, Frost MM, et al. Teleradiology in the local environment. Proceedings of Society of Photo-Optical Instrumentation Engineers, 1991. Vol 1446; 16-23.

The group at the University of Florida is strongly in favor of PACS development, regarding teleradiology as a building block toward a complete PACS, which they intend to implement over a period of time. This paper describes the transmission systems that they are in the process of putting together, including transmission to ICUs, emergency rooms, doctors' offices, and operating rooms; transmission from remote computed radiography units, MR machines, and (in the future) other radiology departments; and transmission to image processing laboratories. In each case they enumerate probable benefits.

Stark DD, Crues JV. Remote diagnosis raises efficiency of radiology. Diagnostic Imaging, 1993. Vol 15, No 11 (November 93); 91-104.

This is a contemporary, upbeat article by two eminent practicing radiologists about the benefits attributable to teleradiology and some of its limitations. Their view is that teleradiology generally supports requirements for increased productivity and efficiency, and that therefore it will come into more widespread use under the impetus of health care reform. Unlike most papers dealing with teleradiology, this one discusses economic, legal, and practical issues.

Stewart BK, Dwyer SJ, Kangarloo H. Design of a high-speed high-resolution teleradiology system. Journal of Digital Imaging, 1992. Vol 5; 144-155.

Among the great variety of PACS-related systems studied and designed by the group at UCLA is a teleradiology system to support imaging activities at several sites elsewhere in the Los Angeles area. Their analysis proceeds under a variety of assumptions about the utilization of the system and methods for implementing it. Their experience is useful to any designer of a new system.

Templeton AW, Dwyer SJ, Rosenthal SJ, et al. Dial-up digital teleradiology system. American Journal of Roentgenology, 1991. Vol 157; 1331-1336.

This paper describes the clinical characteristics of the teleradiology system at the University of Kansas (also described in the paper by Dwyer above). Their general finding is that, although images were changed slightly by teleradiology, image detail is still good and the system is useful for remote primary interpretation.

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